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APPLICATION FOR UNITED STATES PATENT

BY

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# " METHOD OF LACING WINDINGS OF ELECTRIC MACHINES, AND APPARATUS CARRYING OUT THE METHOD".

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## SPECIFICATION

The above named applicant has made an invention or discovery for which the following is a specification.

# METHOD OF LACING WINDINGS OF ELECTRIC MACHINES, AND APPARATUS CARRYING OUT THE METHOD.

## FIELD OF THE INVENTION

The present invention refers to windings of electric machines and more particularly to a method of lacing windings of dynamo-electric machines in general and of electric motors in particular, as well as to an apparatus carrying out such method. The invention has a particularly advantageous application in new generation brushless electric motors, in which the stator has slots with a great angular spacing. However, this is not to be interpreted as a limitation of the possible applications of the invention.

## BACKGROUND OF THE INVENTION

Induction electric motors and generators typically include a stator and a rotor rotatable relative to the stator. The stator comprises a toroidal metal core or body and a plurality of winding coils made of conducting wire, typically copper or aluminum, arranged around the core and capable of generating an electromagnetic field when suitable currents flow therein. The winding coils are generally laced by means of a cord of natural, synthetic or metallic material, in order to improve the winding performance and to avoid possible interference with the moving rotor.

Several techniques and apparatuses for effecting the lacing of stator coils are known, for instance from US-A-3 659 337, US-A-3 862 493, US-A-5 615 472 and US-A-5 485 670. EP-A-1 081 831 in the name of the same applicant discloses a method and an apparatus for making a self-locking knot at the end of the winding lacing.

The known apparatuses employ a cord feeder associated with a needle, the feeder performing a vertical up and down movement (relative to a stator arranged with vertical axis) and an oscillating

movement towards the needle's eye, while the needle hooking the cord and drawing it from the feeder performs both vertical (up and down) movements and radial movements by going into and out of the region defined by the circular perimeter of the stator (more precisely of the coil).

The cord is captured by the open eye of the needle, i.e. by the hook-shaped needle portion (head). The needle, when leaving the region defined by the coil circular perimeter, is rotated in order it does not engage the cord chain of the previous loop, and in order to be positioned again with the hook in the proper orientation for the subsequent cycle.

The known apparatuses allow a satisfactory lacing only for very well formed stator windings, with rather closely angularly spaced slots, that is with a reduced slot pitch.

The stator winding may exhibit irregularities and deformations and, in the known lacing systems, the imperfections of the coil heads to be laced cause a forced deviation of the lacing cord that therefore leaves the area, defined at the initial set-up, foreseen for the engagement between the cord and the needle's eye. Consequently, a lacing stitch can be missed, with the consequent need to stop the apparatus, to make the operator intervene and to discard the stator (which will be recovered later on). This implies a considerable time and labor waste, increasing the lacing cost.

Moreover, in the known lacing systems, in order to make a synchronized and unidirectional phasing of the various movements necessary to perform the lacing, the indexed rotational movement of the stator presenting the different slot intervals to the needle is unidirectional (either clockwise or counterclockwise, depending on the manufacturer's choices). This gives rise to problems of compatibility of use among apparatuses of different manufacturers.

Lastly, for design reasons, the slots may have a great angular spacing and, under those conditions, typical of the new generation

brushless motors, the known methods experience difficulties in correctly performing the lacing.

In the known systems the physical set-up between the needle and the cord feeder is often complex and requires continuous and very precise adjustments to synchronize the meeting or hooking point between the cord feeder and the needle.

## SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the limitations and the drawbacks of the prior art and in particular to provide a method and an apparatus for coil lacing in an electric machine, which method and apparatus allow lacing even very irregular coil heads, simplify the set-up operations and securely fasten the lacing cord to the needle's eye, while reducing the component weight and making the movements of said lacing apparatus smoother.

The above and other objects are achieved through a method of coil lacing in an electric machine, as claimed in claim 1.

In accordance with a further aspect, the invention provides an apparatus for coil lacing in electric machines, as claimed in claim 7.

Further advantageous features are the subject matter of the dependent claims.

The invention will now be described in greater detail with reference to the attached drawings, given by way of non-limiting example.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a fragmentary cross-sectional view showing part of a stator and the relative positions of the needle and the cord feeder when the needle is above the coil to be laced.

Figs. 2A through 2E show the winding lacing steps according to the method of the invention when the needle is above the coil.

Fig. 3 is a fragmentary cross-sectional view showing part of a

stator and the relative positions of the needle and the cord feeder when the needle is below the coil to be laced.

Figs. 4A through 4E show the winding lacing steps according to the method of the invention when the needle is below the coil.

Figs. 5A, 5B and 5C are graphs respectively showing the axial and radial strokes of the needle and the rotation (angular position) of the primary shaft controlling the rotation of the cord feeder and the needle.

Figs. 6A through 6C show in succession the cord hooking modalities at the end of the lacing cycle.

Fig. 7 is a side view of a coil lacing apparatus according to the invention.

Fig. 8 is a top view of the apparatus shown in Fig. 7.

Fig. 9 is a cross-sectional side view of the eccentric control unit shown in Fig. 7.

Fig. 10 is a front view of the detail shown in Fig. 9.

Fig. 11 is a schematic view of the optimum position of the needle's eye at the end of the cord capture step from the feeder, relative to the last chain link.

## DESCRIPTION OF THE PREFERRED EMBODIMENT OF THE INVENTION

Referring to Fig. 1, stator 1 of an electric motor with cylindrical symmetry is partially shown, the stator comprising a stator core 2 and windings or coils 3. The stator is mounted with vertical axis onto a rotatable support (not shown in the Figure).

A needle 10, the structure of which will be disclosed in more detail below, is radially arranged with respect to stator 1 and it can perform an axial stroke denoted by A, a radial stroke denoted by C and a rotation denoted by F. A tubular cord feeder 20 has an end with axis parallel to the needle axis and dispensing lacing cord 4 that is hooked by the needle and made to wrap around the stator coils. The feeder can perform an axial stroke denoted by B and a

rotation, denoted by D, about the needle axis. Lastly, the stator support can be bidirectionally rotationally indexed, as schematically denoted by E, in steps depending on the slot pitch.

Needle 10 comprises a generally cylindrical or conical body 11, of which one end is connected to a driving mechanism (not shown in Fig. 1), whereas the other end is shaped so as to form an open eye with a thinner portion 12, the end section of which is bent into a hook so a to leave a gap or stroke 13 between the hook end and the beginning of the thicker cylindrical portion.

The lacing method with cord wrapping according to the invention will be now described with reference to Figs. 2A through 2E, which are cross sectional views taken along line II-II in Fig. 1 and centered on the axis of needle 10.

For sake of simplicity, an arrangement is disclosed in which the angular rotation speed of the feeder is constant and twice the angular rotation speed (also constant) of the needle about its axis.

Preferably, the method of the invention requires that the two average speeds be in a 2:1 ratio, so that the positions taken at the end of the cycle are as shown in Figs. 2A and 2E. Yet it is possible to envisage that the ratio of the rotation speeds of the feeder and the needle is different, or that such speeds are not constant and change for instance depending on the position reached, in particular depending on the orientation of the cord chain being formed, which determines the need of needle return with the eye so oriented that it does not interfere with a link of the previous chain.

Fig. 11 shows the optimum orientation of the needle's eye relative to the last chain link. In this arrangement, the plane of the needle's eye, denoted in the Figure by reference P, must be perpendicular to major axis S of the ellipse defined by chain link L.

In the situation shown in Fig. 2A, needle 10 is positioned with eye 9 upwards and back 8 downwards, and it rotates counterclockwise about its axis. Feeder 20 is in turn located beside

the needle, with its axis parallel with the needle axis, and cord 4 leaves the feeder downwards. Also feeder 20 rotates counterclockwise about the needle axis, yet with angular speed twice that of the needle. Needle 10 is radially displaced towards the stator center.

In the situation shown in Fig. 2B, needle 10 has rotated by 45°, whereas feeder 20 has rotated by 90° about needle 20 thereby bringing cord 4 in contact with back 8 of needle 10. Cord 4 is deposited onto needle 10 near (shortly before or shortly after) the end of the radial stroke (arrow C) of needle 10 towards the stator inside.

Upon a further rotation of needle 10 and feeder 20, the situation shown in Fig. 2C is reached: here needle 10 has rotated by 90°, whereas feeder 20 has rotated by 180° and is now located on the opposite side with respect to Fig. 2A. Cord 4 is wrapped by about 90° around back 8 of needle 10.

Upon a further rotation of needle 10 and feeder 20, feeder 20 continues rotating and wraps cord 4 around the thin portion of needle 10 (Fig. 2D), that is eye 9, and reaches its final position similar to that of Fig. 2A: here however the needle is turned by 90° (i.e. the needle back is turned upwards) and cord 4 is wrapped around needle 10 and is engaged by the latter as far as the radial displacements (arrow C) are concerned. It is to be appreciated that cord wrapping takes place in portion 13 of eye 9.

Figs. 3 and 4A through 4E, the latter being cross sectional views taken along line IV-IV in Fig. 3, show the lacing steps when needle 10 is below the coil in the gap between adjacent slots. Being the arrangement specular, with needle 10 and feeder 20 rotating clockwise, the considerations made above apply also to these Figures.

Figs. 5A, 5B and 5C are graphs respectively showing the axial and radial displacements of the needle (Figs. 5A, 5B) and the

angular displacements of the primary shaft controlling the needle and feeder rotation.

More particularly, graph 5A shows the axial stroke of the needle over a cycle extending over an arc of 360° from a position above the coil to be laced to a position below the coil.

Graph 5B shows the radial stroke of the needle over the same cycle of 360°, comprising portions in which the needle move towards and away from the stator center with constant angular speed.

Lastly, graph 5C shows the rotation, over a cycle of 360°, of the primary shaft controlling the needle and feeder rotation, the upper graph portion referring to clockwise rotation and the lower portion to counterclockwise rotation.

Those Figures show that, in the interval between points N and Q in the graph of Fig. 5A, where the needle is below the coil, the radial movement of the needle brings it towards the stator center (point R in the graph of Fig. 5B) and then away from the center. At that dead point, the needle has rotated by 180°, as shown before, and the feeder has rotated by twice that angle, i.e. by 360°. As an indication, the graph of Fig. 5C shows that the 180° rotation of the needle and the 360° rotation of the feeder take place within an interval of about 35°, in the 360° cycle, about said dead point.

Turning now to Figs. 6A to 6C, the cord locking at the end of the lacing cycle is now disclosed.

When the lacing cycle is over, knotting is performed, for instance as disclosed in EP-A-1 081 831. When the lacing cycle is almost over, with the needle in the axial stroke above the coil, while feeder 20 is about to perform the last rotation about needle 10 (see Fig. 6A showing a situation similar to Fig. 2A), an external arc-shaped engaging member (or hook) 7 intervenes and radially moves (in direction G shown in the Figures) towards needle 10, so that cord 4 is deposited and wrapped on said arc-shaped member

7 (Fig. 6B). At the cycle end (Fig. 6C), member 7 is moved radially away from the needle (radial return stroke) up to an abutment 6 blocking cord 4, the cord terminal being automatically located within the needle's eye for the subsequent cycle. The cord is then cut at point 15.

In the lacing method of the invention, thanks to the wrapping of the cord on the needle, a twisting of the cord chain being formed is also obtained, which twisting blocks or tightens each chain stitch formed, thereby obtaining a tighter lacing.

The movements required by the method of the invention are synchronous movements, which can be performed by both mechanical and electro-mechanical systems, and this allows in any case incrementing the lacing speed without negatively affecting the life of the moving parts.

Moreover, the physical set-up of the needle and the associated feeder is extremely simplified.

Advantageously, the feeder and the needle are operated through a single driving device.

The method of the invention allows lacing very irregular windings or windings with a great angular spacing between the slots, such as for instance the stator windings of new generation brushless motors. Moreover, the method allows performing the lacing even changing the stator rotation direction, for instance first in clockwise direction and then in counterclockwise direction, to perform two or more lacing cycles on a same coil portion.

Moreover, the apparatus mechanics is lighter, thereby allowing increasing the operation speed, the set-up operations by the operator are simplified and the lacing is firmer thanks to the twisting carried out on each chain or loop of the lacing cord.

Moreover, the use of a rotating feeder solves a number of problems associated with the cord failing to meet the needle's eye due to one ore more of the following situations: non perfectly

uniform coil heads, great thickness of the copper wire of the coil, irregular coils as is for instance the case of multipole windings.

Referring to Fig. 7, the apparatus for carrying out the method of the invention comprises a needle 10 and a feeder 20 carried by a support vertically movable along guides 15. An eccentric control assembly 25 controls the rotational movement of feeder 20 about the needle axis. A connecting rod - crank assembly, of which connecting rod end 17 is shown in Fig. 7, vertically moves the support along guides 15, whereas a crank 23 (Fig. 8), hingedly connected to a sleeve 19 through a transmission 21 so as to reciprocate, generates the needle radial movement into and out of the coil. Eccentric control assembly 25 of feeder 20 is shown in greater detail in Fig. 9, which shows a primary shaft 41, from which said assembly is driven, and a seat 43 in which support 45 (shown in Fig. 7) of feeder 20 is secured.

Fig. 10 shows a detail of the arrangement generating the rotary movement of feeder 20 about needle 10. That arrangement exploits the combined displacement of two plates 31 and 33, which are slidable on roller bearings in vertical and horizontal direction, respectively, so as to make the bent end of feeder 20 rotate about the axis of needle 10 without upsetting the feeder tube, while keeping vertical the axis of the feeder portion secured to said support 45.

Primary shaft 41 of the eccentric assembly is driven by a distributor 47 in correspondence of which the alternating rotation of a crescent-shaped gear 49 is shared among said shaft 41 and shaft 51 supporting needle 10.

Said crescent-shaped gear 49 is driven into rotation, alternately in clockwise and counterclockwise direction, by a universal joint 53 arranged at the output from a transmission assembly 55 driven by an oscillator, not shown.

Shaft 41 controlling eccentric assembly 25 and shaft 51 of

needle 10 mesh with said crescent-shaped gear 49 through corresponding gears 57, 59, suitably dimensioned so as to achieve the proper reduction ratio and to make shafts 41 and 51 rotate by the desired angle.

Preferably, all movements are imparted by a single motor, even if using several electronically controlled motors, e. g. one for each movement, is within the scope of the invention. Clearly, in the latter case the needle and the feeder can easily be made to perform both rotational and translational variable speed movements, so as to suit the different situations in a same winding. For instance, the ratio of the needle and feeder rotations can be varied depending on whether the needle is above or below the coil, or yet depending on whether the stator is rotationally indexed clockwise or counterclockwise.

Lastly, it is to be appreciated that generally the apparatuses concerned have an upper and a lower winding of similar shape and size. In such case the apparatus of the invention will comprise, in conventional manner, two sets of the components described above, operating in specular manner to lace both windings at the same time.

It is clear that the above description is given only by way of non-limiting example, and that changes and variations are possible without departing from the scope of the invention.